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| User’s Guide |
| Lab 2 Group BEERZ |
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# Introduction

# Installing the Software

The WI11 Assembler can run on any platform that supports Java Runtime Environment. The assembler does not require much disk space; it takes up approximately 2 MB of space, and minimal memory.

After unzipping the program in the desired directory, the program must be compiled. The instruction would be as follows;

> javac Main.java

To run the program, see the section on compiling a program.

# Writing a Program

## Required Software

In addition to the installation of the assembler (discussed in the section above), you can use any basic word processing software such as Emacs, Notepad, or Notepad++, to write an assembler program. When saving, the file must have the extension .asm, marking an assembly file.

## Structure

To write a program for this assembler, you must format your file as follows. If you chose to omit a Label or the operation code does not take up all the spaces allotted below, leave those spaces blank. The numbers in the second row indicates the position of a character in a record. There can be white space between the individual arguments in a record, but otherwise the format needs to strictly be followed.

The beginning of a comment is noted with a semicolon (;). Anything after a semicolon is ignored by the Assembler. Please see the

## Header Record

A header record must be the first record in your program, although you may have multiple lines of comments before the header record. You must have a label for the header record; this will serve as your segment name. After three blank spaces, you should have the pseudo-operation code for the beginning of a program, .ORIG. The operand for this record is optional. If you wish to specify an absolute address at which the program should be loaded from, this number needs to be in hexadecimal, and needs to be in the range of x0 to xFFFF. If the operand is omitted, the program is considered to be relocatable (see the section below on relocatable programs for further details).

### Relocatable Programs

A program is considered relocatable if the programmer does not specify a location in memory where the program should be loaded. This allows more flexibility in allotting a properly sized block in memory for the program; this will be done by the program and not by the user.

## Text Records

Text records are the commands you wish the program to execute. The various components are described in further detail below.

### Labels

Labels can be used to refer to a specific record, memory location, or value in your program. You can have a label on any record, except for the end record. A label can be composed of up to 6 alphanumeric characters (no spaces), but cannot begin with “R” (upper case) or “x” (lower case). Both upper case and lower case characters can be used in labels. Additionally, the labels are case sensitive.

### Instructions

There are three categories of instructions, described in further detail below; Arithmetic, Loading and Storing, and Flow of Control instructions.

#### Arithmetic Instructions

There are three Arithmetic instructions available in the assembler; ADD, AND, and NOT. All of these instructions modify the CCRs, which are used for Flow of Control operations. The CCR is modified according to whether the result of the operation is positive, negative, or zero.

##### Add

The ADD instruction will perform the addition arithmetic operation on two specified arguments, and store the result in a specified register. The instruction can either add two registers together, or add a register and an immediate operand (for further information on immediate operands, please see the Operands section). They would be formed as follows;

ADD DR, SR1, SR2 ;Adds two registers together.

ADD DR,SR1,imm5;Adds a register with a immediate operand.

DR represents the location where the result of the operation will be stored; SR1 and SR2 represent the registers where the arguments are stored, and imm5 represents an immediate operand.

Example: To add registers 1 and 2 together, and store the result in register 4, the record should be

ADD R4, R1, R2 ;R1+R2=R4

Example: To add register 1 with xA0, and store the result in register 1, the record would be

ADD R1,R1,xA0 ;R1+xA0=R1

##### And

The AND instruction will perform a bitwise and operation on two specified arguments, and store the result in the specified register. The instruction can either and two registers, or and a register with a immediate operand (see Operands section for further information). The instructions would be formed as follows;

AND DR,SR1,SR2 ;Ands two registers together

AND DR,SR1,imm5;Ands a register with an immediate.

DR represents the location where the result of the operation will be stored; SR1 and SR2 represent the registers where the arguments are stored, and imm5 represents an immediate operand.

Example: To and registers 4 and 5 together, and store the result in register 0, the record would be

AND R0, R4, R5 ;R4 and R5 = R0

Example: To and register 1 with x0, and store the result in register 1, the record would be

AND R1,R1,x0;R1 and x0 = R1

##### Not

The NOT instruction will perform a bitwise not operation on a register, then store the result in a specified register. The instructions would be formed as follows;

NOT DR,SR

DR represents the location where the result of the operation will be stored, and SR represents the register where the argument should be stored.

Example: To not register 1, and store the result in register 6, the record would be

NOT R6,R1 ;~R1 = R6

#### Loading and Storing Instructions

There are seven load and store instructions available for use. Four instructions, LD, LDR, LDI, and LEA load data from memory and store it in a given register. Three instructions, ST, STR, and STI, write data from the given register to a given memory location. Only instructions that load data from memory change the CCRs; they are changed depending on whether the data loaded is negative, positive, or zero. CCRs are used for Flow of Control instructions; please see the section on Flow of Control for further information.

The instructions will be categorized by their addressing mode; the differences between these modes will be explained in their respective sections.

##### Immediate Addressing

There is one Immediate Addressing operation, Load Effective Address (instruction code LEA). This instruction concatenates bits 15 through 9 of the Program Counter with bits 8 through 0 specified in the instruction. The result is stored in the register specified by the programmer. The instruction is formed as follows;

LEA DR,addr

DR represents the destination register where the result will be stored, and the addr represents the address to be concatenated with the Program Counter.

Example: If the Program Counter is x3000, to load address x31A0 (or concatenate pgoffset x1A0 with the Program Counter) in to register 4, the instruction would be as follows;

LEA R4,x1A0 ; Loads address x31A0 into register 4

Example: If the Program Counter is x4200, to concatenate the PC with address Addr1 (a label that represents value x7094), and store the result in register 3 , the instruction would be as follows.

LEA R3, Addr1 ; Loads address x4294 in to register 3

##### Direct Addressing

There are two Direct Addressing operations, Load (LD) and Store (ST). In Direct Addressing, the address where data is loaded or stored is specified in the instruction. The address is formed by concatenating bits 15 through 9 of the Program Counter with bits 8 through 0 of the instruction. In the Load instruction, data is loaded from the specified memory location and stored in the given register. In the Store instruction, data is stored in the specified memory location, the source being the specified register. The instruction format is as follows;

LD DR,addr

ST SR,addr

DR represents the destination register where the result will be stored. SR represents the source register where the data to be stored is located. The addr field represents the address that should be used to form the address that data will be loaded or stored.

Example: If the value of the Program Counter is x2130, to store the data in register 4 at address x20E0, the instruction would be as follows;

ST R4,xE0; Contents of R4 stored at address x20E0

Example: If the value of the Program Counter is x39, to load the data from address x10E into register 1 (label Value represents value x10E), the instruction would be as follows;

LD R1,Value; Contents of x10E are loaded to R1

##### Indirect Addressing

There are two Indirect Addressing operations, Load Indirect (LDI) and Store Indirect (STI). In Indirect Address mode, the address where data is loaded or stored is formed by loading the address from the memory location specified in the instruction. The memory location where the address is stored is formed by concatenating bits 15 through 9 for the Program Counter with bits 8 through 0 of the instruction. For the Load Indirect instruction, data is loaded from the address stored in the specified memory location, and is loaded into the given register. For the Store Indirect instruction, data is stored at the address stored in the given memory location, the source of the data being the specified register. The instruction format is as follows;

LDI DR,addr

STI SR,addr

DR represents the destination register where the result will be stored. SR represents the source register where the data to be stored is located. The addr field represents the memory location where the address for the data to be loaded or stored is located.

Example: If the value of the Program Counter is x3000, to store the data in register 1 at the address stored in location x31FF, the instruction would be as follows;

STI R1,x1FF

Example: If the value of the Program Counter is x14, to load data from the address stored at location xA, and store it in register 3, the instruction would be formed as follows;

LDI R3,xA

##### Register Indexed Addressing

There are two Register-Indexed Addressing operations, Load Register-relative (LDR) and Store Register-relative (STR). In Register indexed addressing mode, the address where the data is stored or loaded is formed by adding a zero-extended six bit offset (index6) to a given base register. The instruction format is as follows;

LDR DR,BR,index6

STR SR,BR,index6

DR represents the destination register where the result will be stored. SR represents the source register where the data to be stored is located. BR represents the base register that will be used to form the store or load location. The index6 represents the integer to be added to the base to form the store or load location.

Example: To store the data in register 2 at the address formed by register 3 (as the base register) and by xFF, the instruction would be as follows;

STR R2,R3,xFF

Example: To load the data stored at the location formed by register 1 (as the base register) and by INDEX1 (a label representing x40) into register 2, the instruction would be as follows;

LDR R2,R1,INDEX1

#### Flow of Control Instructions

Flow of Control instructions do several things; allow the program to jump to a specific record in a program, to control input and output, and allow the program to use subroutines. The instructions are described in more detail below.

##### Branches

A branch is a conditional instruction that will change the program counter to the given address in the operand if the conditions specified are true. The address that the program will branch to is formed by concatenating bits 15 through 9 of the program counter with bits 8 through 0 of the address in the operand.

The branch instruction depends on what the conditions are for the branch to occur. After “BR”, the CCR conditions should be listed in order of the CCRs; N (Negative), Z (Zero), and P (Positive) can all be added after BR, and must be added in that order. The CCRs of the machine are changed after any Arithmetic or Load instruction, depending on the result of the command.

Example: If the program counter is equal to x3100, to branch if the CCRs are set to either negative or positive to x3156, the instruction would be as follows;

BRNP x3156

Example: If the program counter is equal to x10, to branch unconditionally to x40, the instruction would be as follows;

BRNZP x40

The instruction x0000, which is a never branch, is also known as a no-op. This instruction will not execute anything, yet the program counter will be incremented.

##### Traps

A Trap instruction controls several specific functions of the machine. The instructions for these are formed by the Trap instruction code (TRAP), followed by the trap vector for the function desired.

A symbol that equals the trap vector integer can replace a constant trap vector.

###### Input

There are two forms of Input instructions; one prompts the user for a character (IN, x23), the other prompts the user for a decimal integer (INN, x33). The data input by the user is stored in register 0 (for a character, the ASCII code is stored in the register).

The CCRs are changed according to the data input by the user.

Example: To prompt the user for a character to be stored in register 0, the instruction would be as follows;

TRAP x33

###### Output

There are three forms of Output instructions; one outputs a character from register 0 (OUT, x21), another prints out a string whose starting point is the address stored in register 0 (PUTS, x22), and the last prints out a decimal integer stored in register 0 (OUTN, x31).

Example: To print out the integer stored in register0, the instruction would be as follows;

TRAP x31

Example: To print out the string “Test”, if the first character’s address is stored in register 0 (and the symbol PUTS equals x22), the instruction would be as follows;

PUTS .EQU x22

TRAP PUTS

###### Halt

This instruction halts the execution of the program (HALT, x25).

Example: To halt a program, the instruction would be as follows;

TRAP x25

###### Random

This instruction generates a random number, and then stores it in register 0 (RND, x43).

The CCRs are changed according to the number generated.

##### Jumps

There are two types of jumps; jumps to subroutines (JSR, JSRR) and regular jumps (JMP, JMPR). The difference between the two is that the jumps to subroutine instructions copy the address of the Program Counter into register 7. Otherwise, JSR and JMP are the same instruction, as are JSRR and JMPR.

In the JSR and JMP instruction, the destination address is formed by concatenating bits 15 through 9 of the Program Counter with bits 8 through 0 of the instruction. The instruction format is as follows;

JSR addr

JMP addr

The addr operand represents either the symbol or constant used as an addresss.

In the JSRR and JMPR instruction, the destination address is formed by by adding a zero-extended six bit offset (index6) to the given base register. The instruction format is as follows;

JSRR BR, index6

JMPR BR, index6

BR indicated the base register, which is added to index6, to calculate the desired destination address.

Example: To jump to the address formed by the addition of register 1 and x20, the instruction would be as follows;

JMPR R1, x20

##### Returns

The return instruction (RET) copies the contents of register 7 into the Program Counter. This allows a program to return from a subroutine call.

### Operands

There are several different forms of operands that can be used in the operand fields of records; Registers, Constants, Offsets, Immediates, Addresses, Indexes, Symbols, and Literals. To see which forms of operands can be used with a specific instruction, please refer to the section above discussing the requirements for each one.

#### Registers

In the machine, there are eight 16-bit registers. To refer to a register, use a capital ‘R’ followed by the number of the register. Thus, the range of registers possible is R0 to R7.

#### Constants

If an instruction can use constants in their operands, you can use either hexadecimal or decimal numbers. Hexadecimal numbers can be in the range of x0 and xFFFF, and must have a lowercase ‘x’ before the number. Decimal numbers can be in the range of -32,768 to 32,767, and must have pound sign ‘#’ before the negative sign (if present) and the numbers.

#### Immediates (imm5)

If an instruction can have Immediates in their operands, the Immediate must be in the range of -16 to 15 if in decimal, or in the range of x0 to x1F if hexadecimal. Decimal numbers must have the pound sign ‘#’ before the digits (and negative sign). Hexadecimal numbers must have a lowercase ‘x’ before the digits.

#### Addresses (addr)

If an instruction uses Addresses, they must be in the range of x0 to xFFFF (or 0 to 65535 in decimal). When used in an instruction, only the last nine bits (in binary) are used. Decimal numbers must have the pound sign ‘#’ before the digits (and negative sign). Hexadecimal numbers must have a lowercase ‘x’ before the digits.

If the address provided is not in the same memory page as the program counter, the assembler will show an error message.

#### Indexes (index6)

If an instruction uses Indexes, they can be in the range of x0 to xFF (or 0 to 255 in decimal). Decimal numbers must have the pound sign ‘#’ before the digits (and negative sign). Hexadecimal numbers must have a lowercase ‘x’ before the digits.

#### Symbols

Any of the above operands can be replaced by a symbol in a program. A relocatable symbol, or a symbol whose value changes depending on the memory location of the program, can be used only with Branch, Jump Subroutine, Jump, Load, Load Immediate, Load Effective Address, Store, and Store Immediate. Otherwise, an absolute symbol is required, whose value does not change based on the memory location of the program.

Symbols can be used in place of a register name. If done, the absolute symbol must be equal to a value between 0 and 7.

Example: To add the value of registers 1 and 2, and store the result in register 1. The symbol “avalue” will represent register 1, and the symbol “bvalue” will represent register 2.

avalue .EQU x1

bvalue .EQU x2

ADD avalue, bvalue, avalue ; avalue + bvalue = avalue

Symbols can also be used in place of Immediates, Indexes, and Trap Vectors. These must be absolute (most likely using the .EQU function), and must be in the range of the operand it is replacing. When a symbol is used as the last argument in the ADD or AND instructions, it is always assumed to be an Immediate operand, rather than a register.

#### Literals

Literals can only be used with the Load (LD) instruction. If a literal is present, the assembler will assign a location in memory for the literal, then place the value indicated in the reserved memory, and finally use that address in the instruction. To use a literal, place an equal sign ‘=’ in front of a constant. Thus, the value of a literal must be between -32,768 and 32,767 for decimal numbers, and between x0 and xFFFF for hexadecimal numbers.

### Pseudo Operations

Pseudo Operations are instructions that either store a specified value (or values beginning) at a location, or configure storage. There are four pseudo operations (the instructions for the start and end of a program are discussed in a separate section).

#### .EQU

This instruction equates a symbol (given in the label field) with a value given in the operand field. This is analogous to a constant in other programming languages. The value can be a previously defined label or a constant. If a constant, it can be written as a decimal (with the pound sign (#) before it) or as a hexadecimal number (with a lower case ‘x’ before it). This method does not allocate memory.

If the value of the symbol is equated to another symbol, that symbol must be defined earlier in the program.

Example: To set ‘const1’ equal to the value #32, the instruction would be as follows;

const1 .EQU #32

Example: To set ‘const2’ equal to the value represented by ‘const1’, the instruction would be as follows;

const2 .EQU const1

#### .FILL

This instruction creates a word (of memory), that holds the operand specified by the user. The operand can be in either hexadecimal (with a lower case ‘x’ preceding the number) or in decimal (with a pound sign ‘#’ preceding the number). Hexadecimal numbers must be in the range of x0 to xFFFF, and decimals must be in the range of -32,768 and 32,767. Thus, if a symbol is used as the operand, the value of that would need to be in the range of -32,768 to xFFFF. You can give a .FILL record a label if you wish, to refer back to the specific location in memory where the word is stored. However, a label is not required.

Example: To define #-342, the instruction would be as follows;

.FILL #-342 ;Reserves memory location with contents -342

Example: To define x45, and label it with the string “hexnum”, the record would be as follows;

hexnum .FILL x45

#### .STRZ

This instruction creates a block of words (of memory) to hold a string of characters, which should be in the operand field enclosed in quotation marks. The last character is followed by a null word. Thus, the .STRZ function uses one plus the length of the string words in memory. A label is optional; if used, it will refer to the memory location where the first character is stored.

Example: To store the string “Test1” in memory, and link the first character’s location with the label string, the record would be as follows;

string .STRZ “Test1”

#### .BLKW

This instruction creates a block of storage in memory. The operand of this instruction is the number of words to be set aside, in hexadecimal. The number of words needs to be between x1 and xFFFF. In addition to using a constant in the operand field, a previously defined symbol can also be used; the data it contains must follow the previously mentioned guidelines for constants. This block will not contain any data after created. A label is optional; if used, it will refer to the memory location of the first word in the block of memory.

Example: To create a block of x20 words, and label the first word “blkw12”, the instruction would be as follows;

blkw12 .BLKW x20

### Comments

Comments can be formed in two ways; a full line comment or a partial line comment. If the first character of a line is a semicolon (;), then that record is considered to be a comment and will be ignored by the Assembler. Otherwise, a comment needs to follow a properly formed record, and should start after the operands field. Again, the comment should begin with a semicolon (;), and the assembler will ignore any information after the semicolon in the same line.

Example: To insert a comment after a fill instruction, the instruction would be as follows;

exampl .FILL xFF; Any data after the semicolon will be ignored.

## End Record

The end record needs to be the last record in your program. The record should be formed with .END in the operation field. Optionally, a hex integer starting location operand may be specified. If none is given, then the program begins execution at the first address in the segment. If a hex integer between x0 and xFFFF is given, then the program begins to execute at that address.

Additionally, there cannot be any label in this record.

Example: To begin execution at address x300A, the End Record would be formed as follows;

.END x300A

# Compiling a Program

## Commands

The basic command for compiling an assembly program, when your current directory path is where the file is located, with this assembler is as follows.;

>java Main (inputfile) (outputfile) [options]

The input and output files are necessary, while any options specified are not necessary to run the program.

To view the possible flags for the program, omit two files and substitute “--help”.

To see a source code listing for the program, use the “-l” flag in the option field. This will cause the listing to be displayed on the console screen.

Example: To compile file “test.asm” into an object file “test.obj”, and display a listing for the file, the command would be as follows;

>java Main test.asm test.obj -l

## Output

# Debugging Error Messages